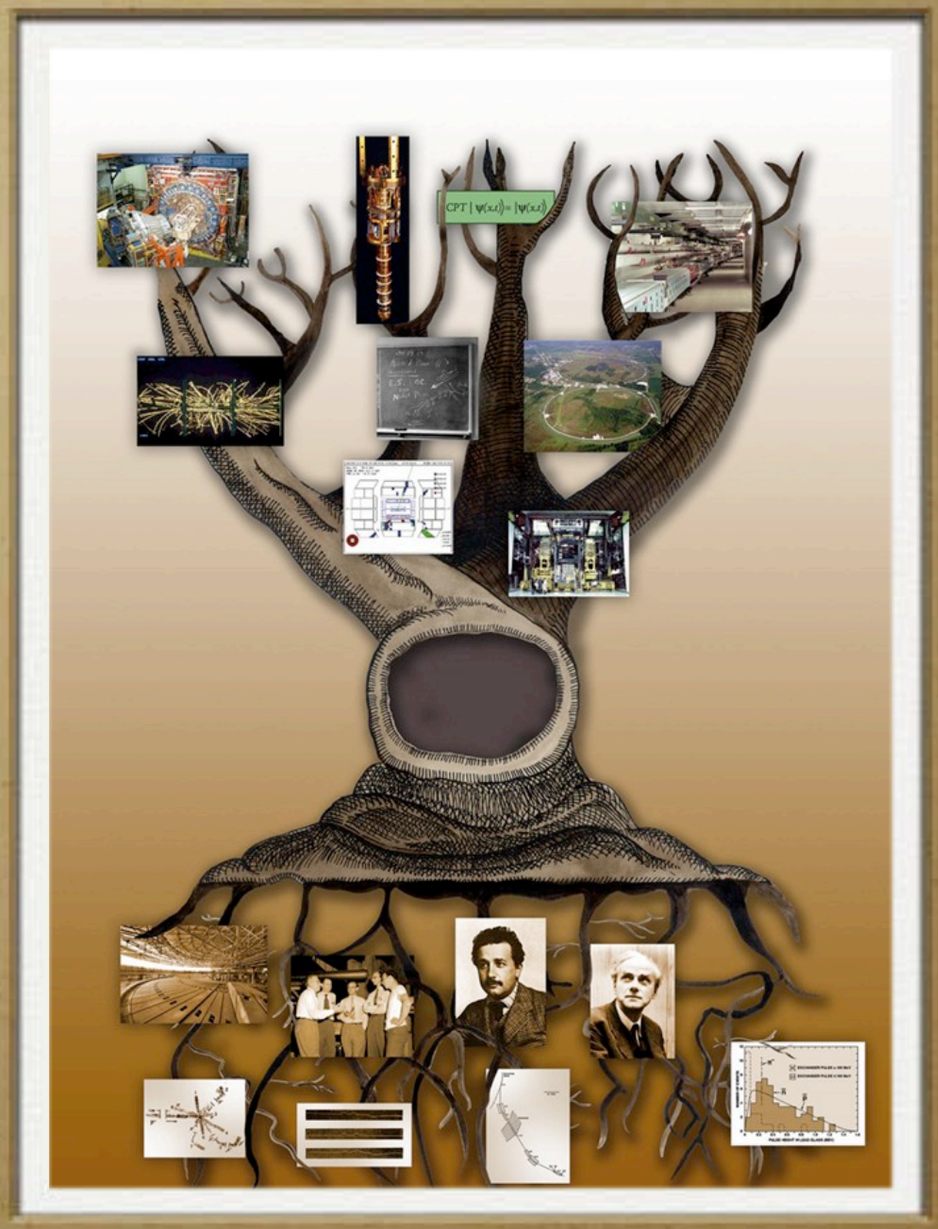
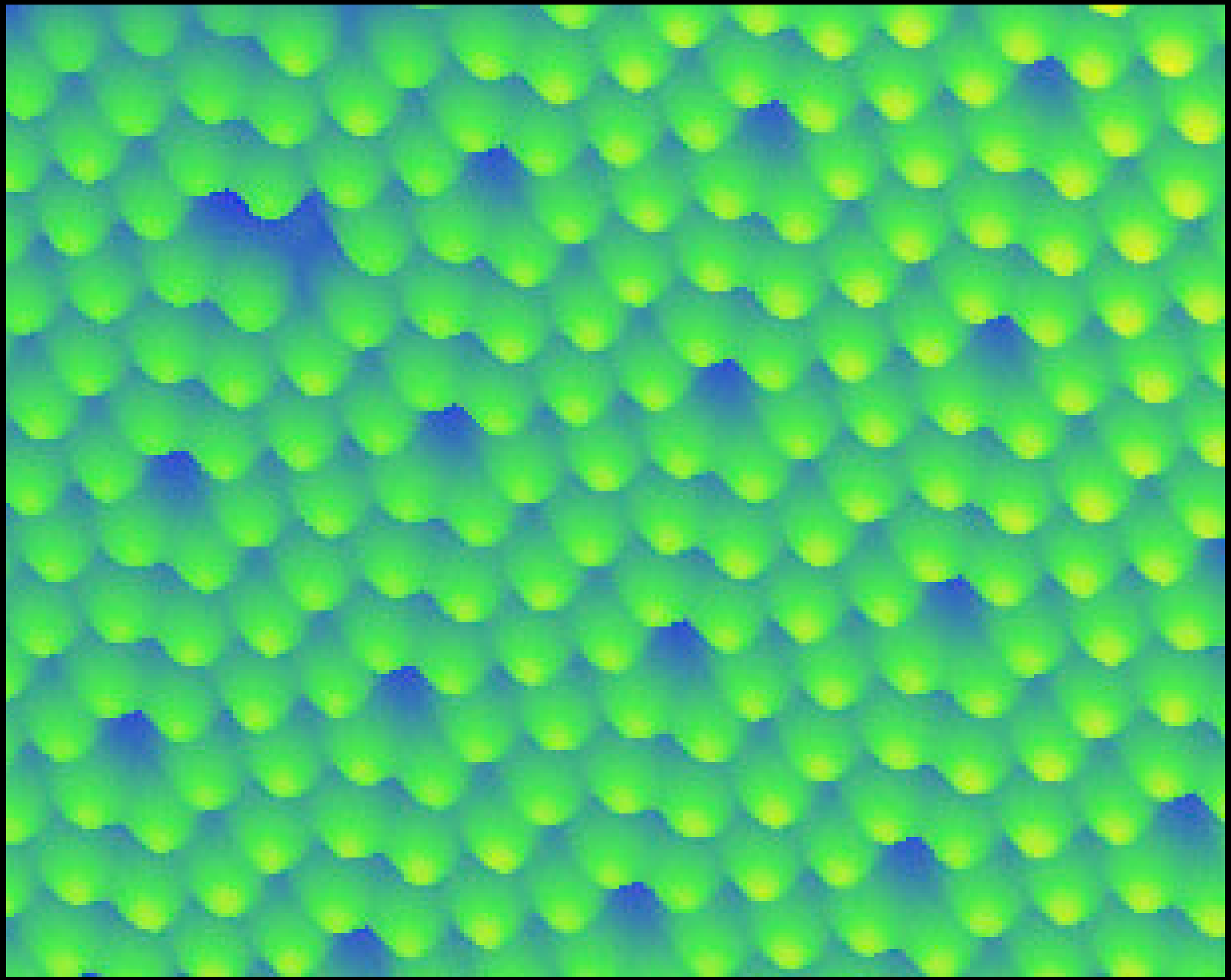
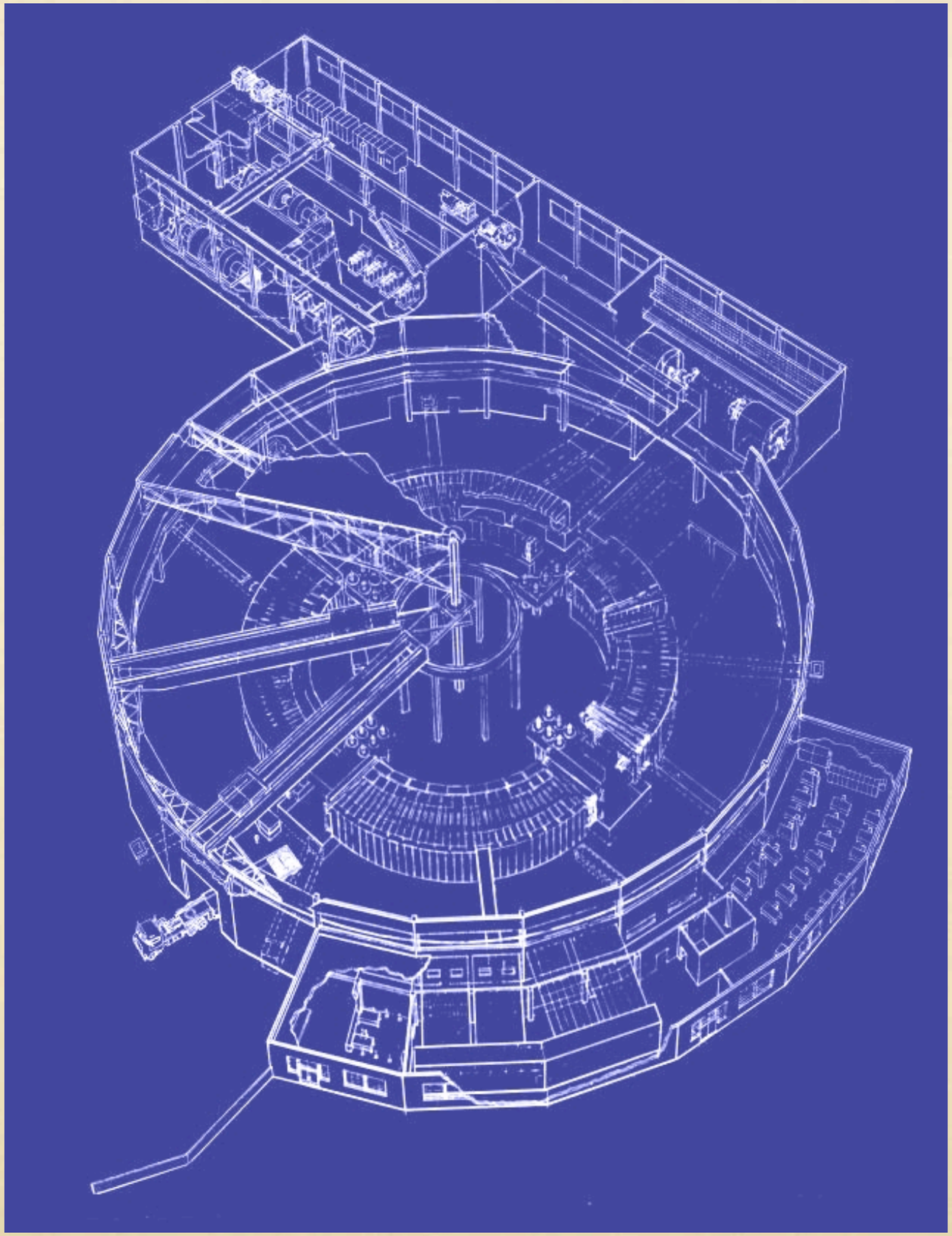
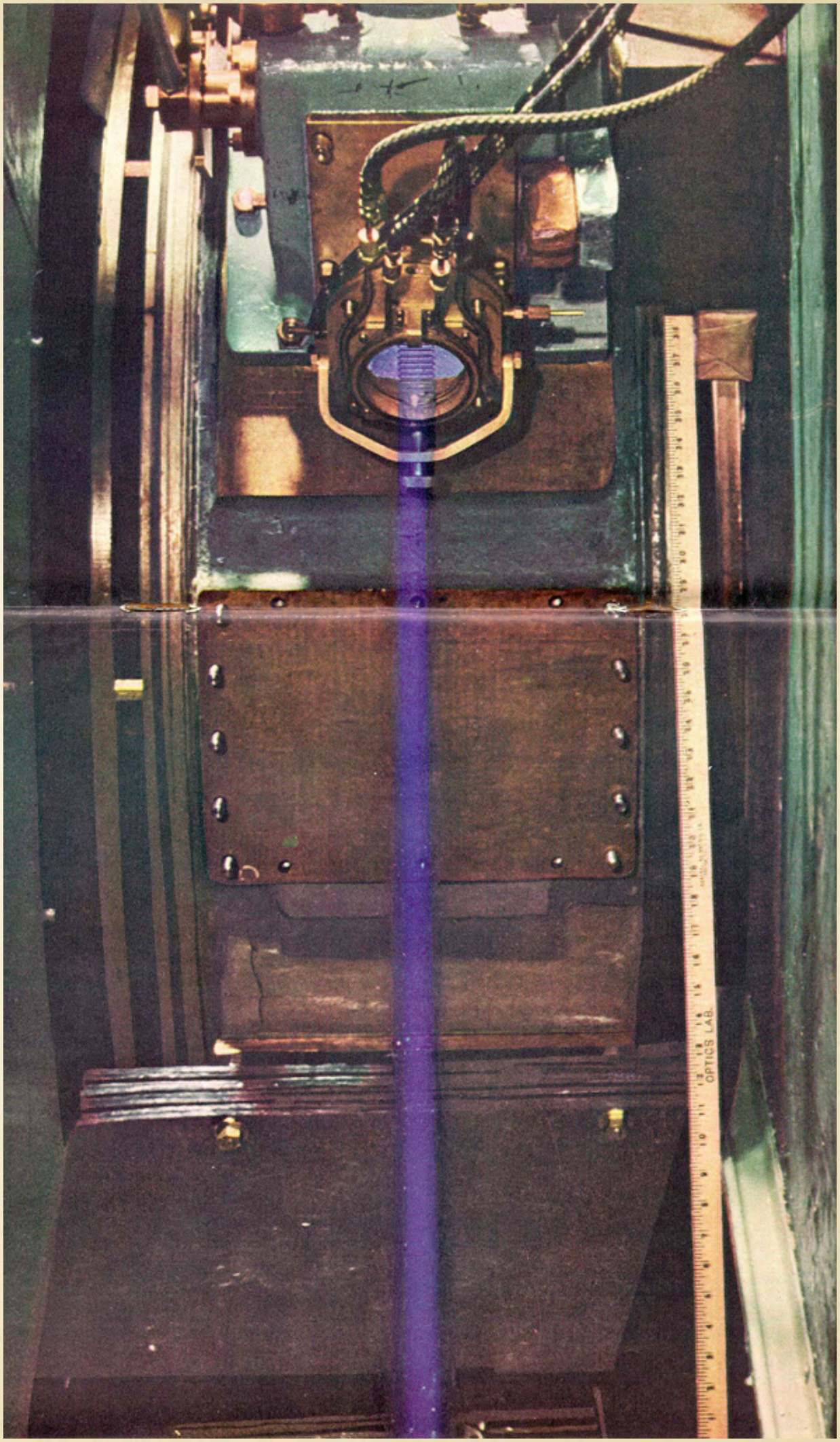
New Worlds

Chris Quigg








BAY SPRINGS LAB

The World's Most Powerful Microscope
nanonanophysics!

Tevatron Collider at Fermilab and its detectors
protons on antiprotons (1 TeV)

speed of light : $c \approx 10^9$ km/h

... of the protons & antiprotons : $c - 495$ km/h

Protons pass my window 45 000 times a second

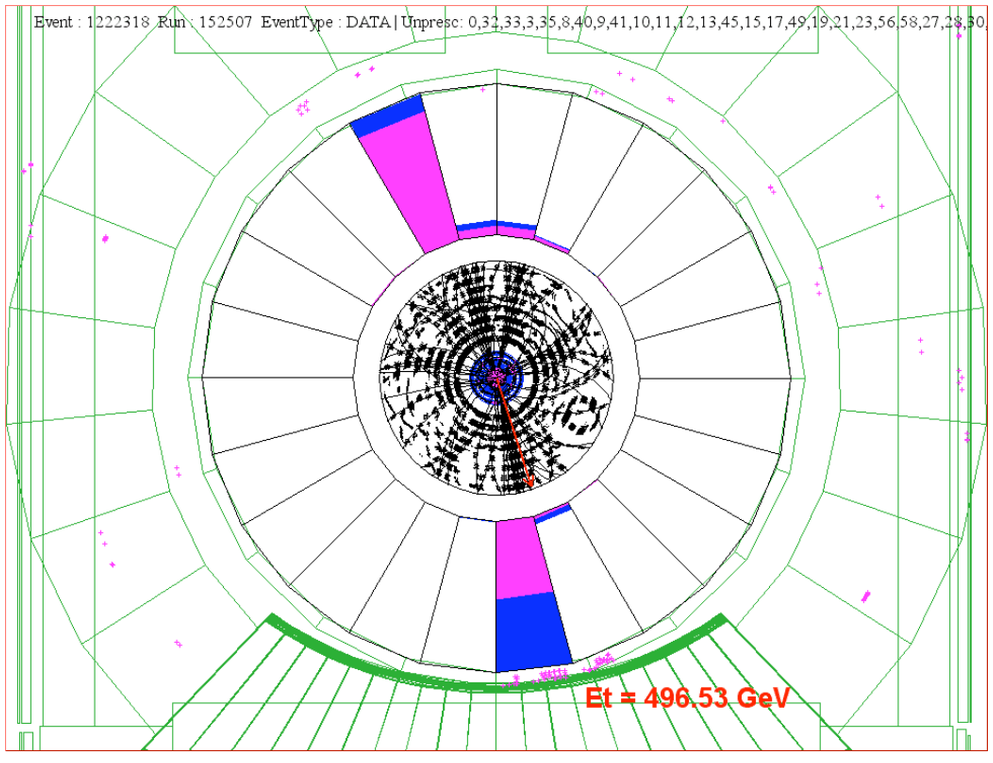
10 millions collisions per second

Run 152507 event 1222318

Dijet Mass = 1364 GeV (corr)

cos θ* = 0.30

z vertex = -25 cm

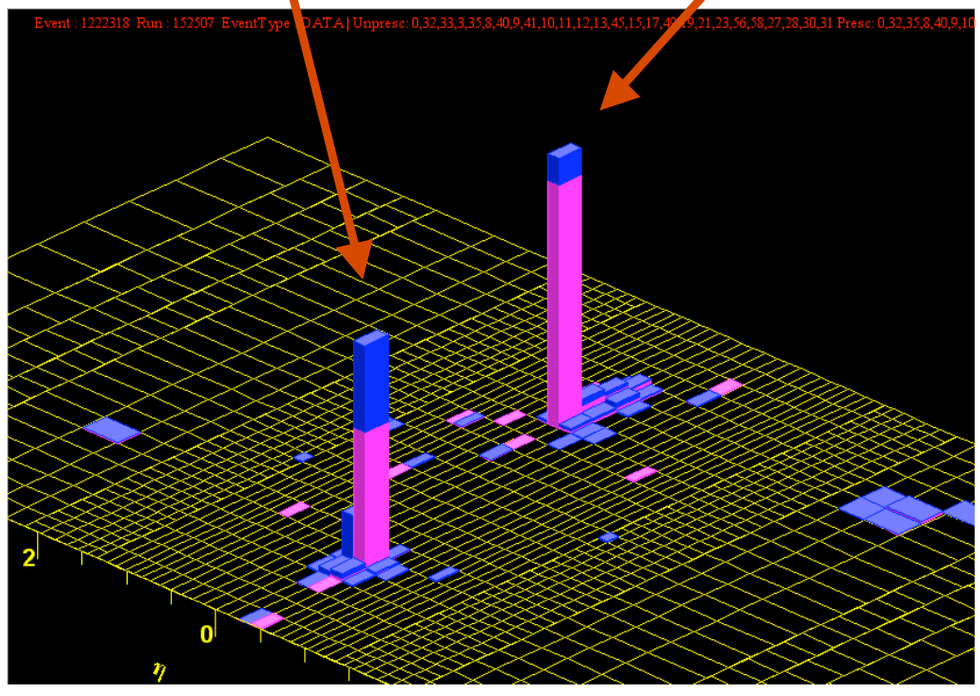


J2 E_T = 633 GeV (corr)
546 GeV (raw)

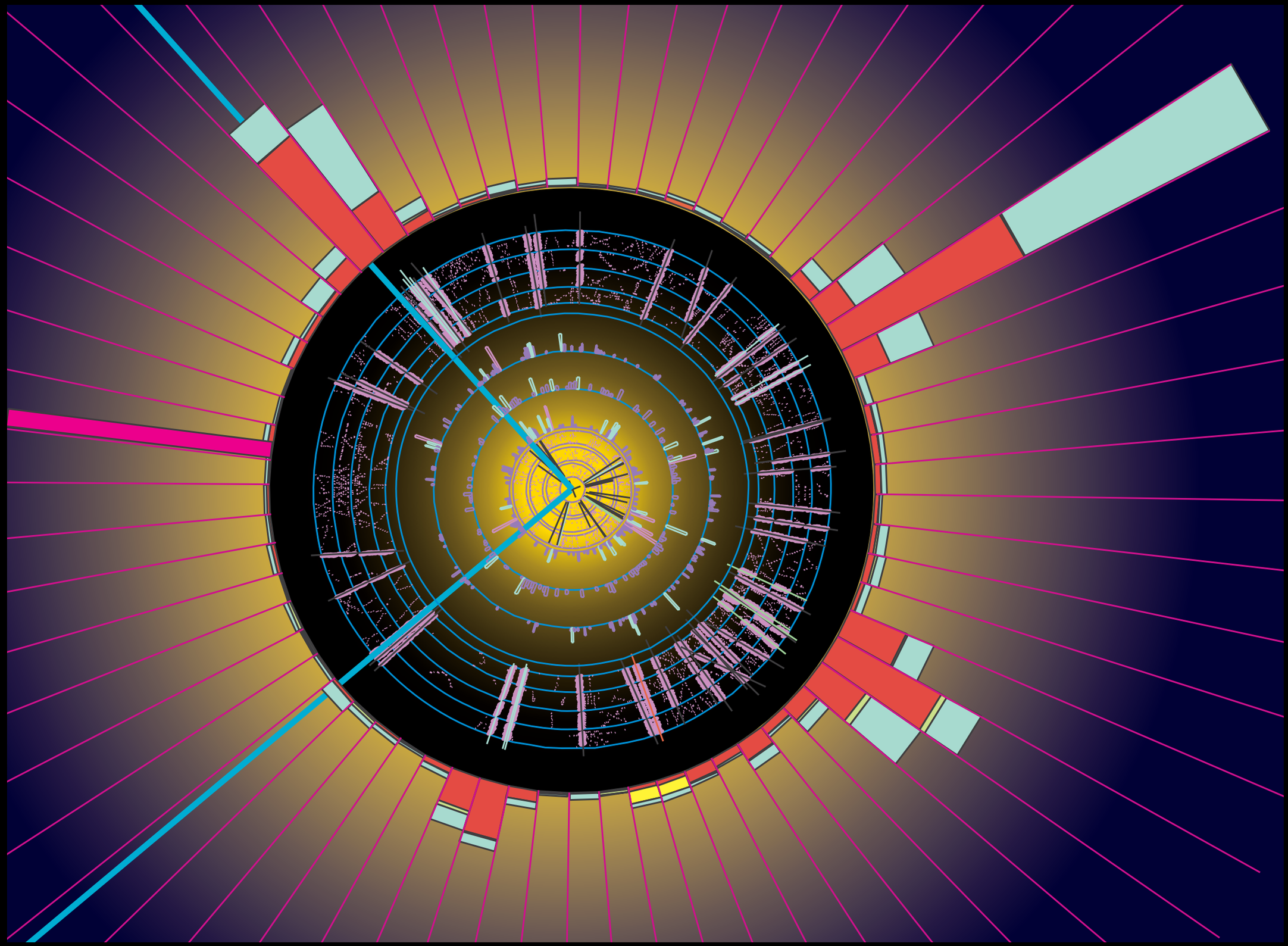
J2 η = -0.30 (detector)
= -0.19 (correct z)

J1 E_T = 666 GeV (corr)
583 GeV (raw)

J1 η = 0.31 (detector)
= 0.43 (correct z)



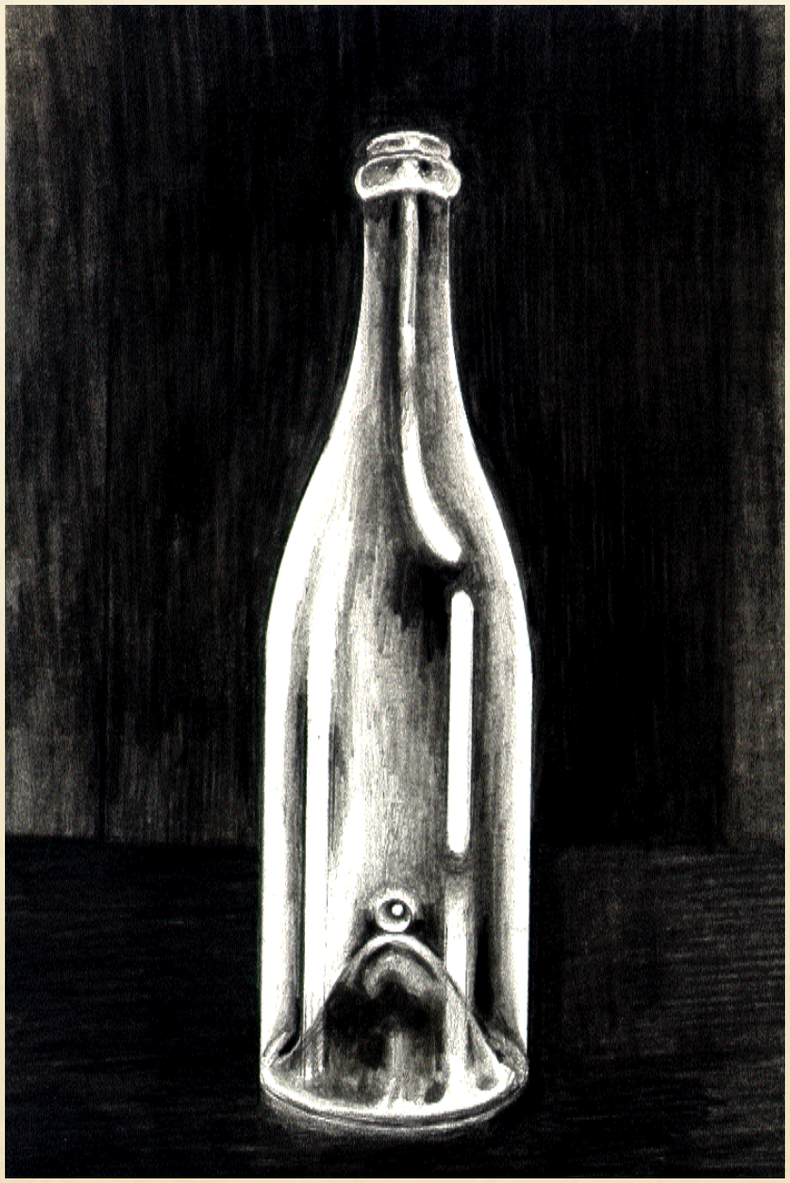
CDF Run 2 Preliminary



Frontier:
Understanding the everyday

- Why atoms?
- Why chemistry?
- Why stable structures?
- What makes life possible?

Symmetry in the laws of nature,
not necessarily in their consequences



Spontaneous symmetry breaking

If the electroweak symmetry were not hidden ...

massless quarks and leptons

proton mass would be little changed ...
but the proton would outweigh the neutron

lightest nucleus: the neutron — no hydrogen atom

some light elements produced in the big bang

but the radius of atoms is infinite

no chemistry, no liquids, no solids

A mysterious new force hides electroweak symmetry

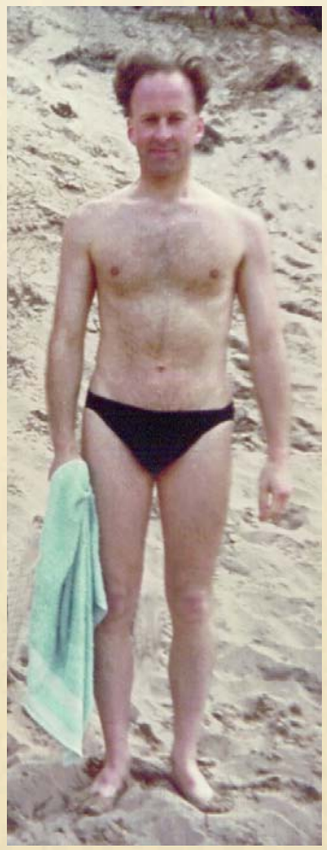
- New kind of force? Higgs field?
- New force from a new symmetry?
- Residual force from strong dynamics?
- Echo of extra spacetime dimensions?

Which path has nature taken?

Experiments at 1 TeV will tell

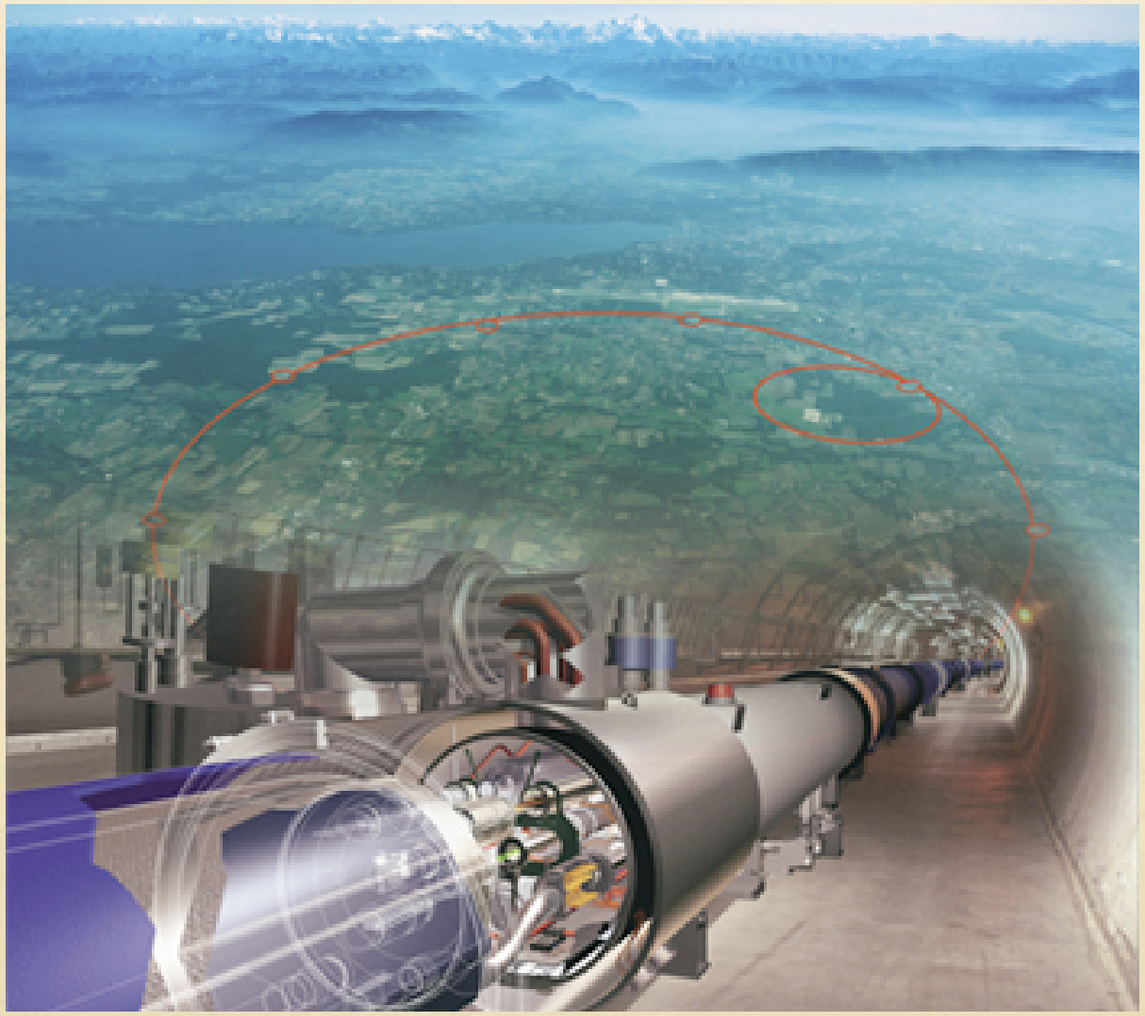
Searching for the *agent provocateur* of electroweak symmetry breaking

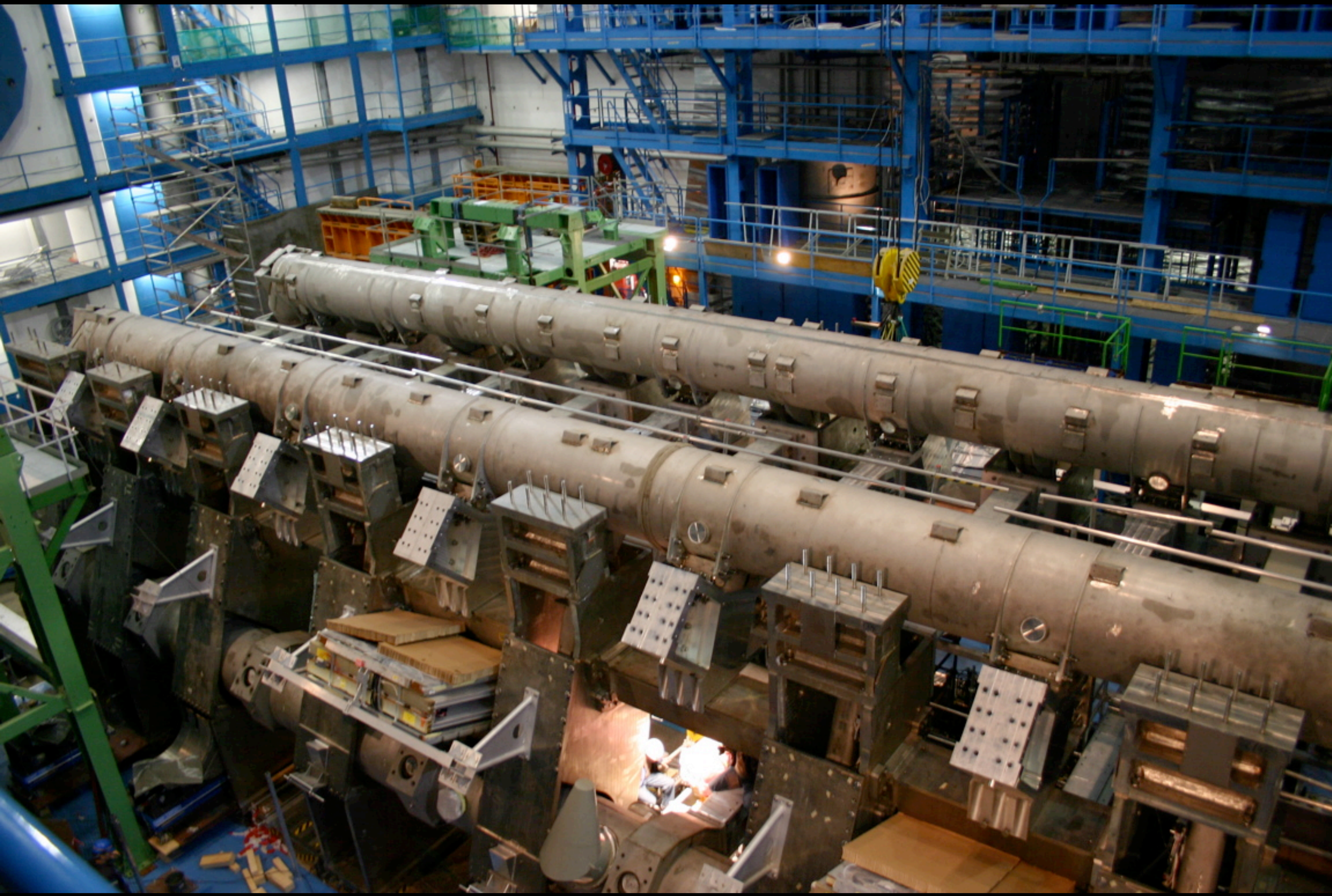
« the search for the Higgs boson »

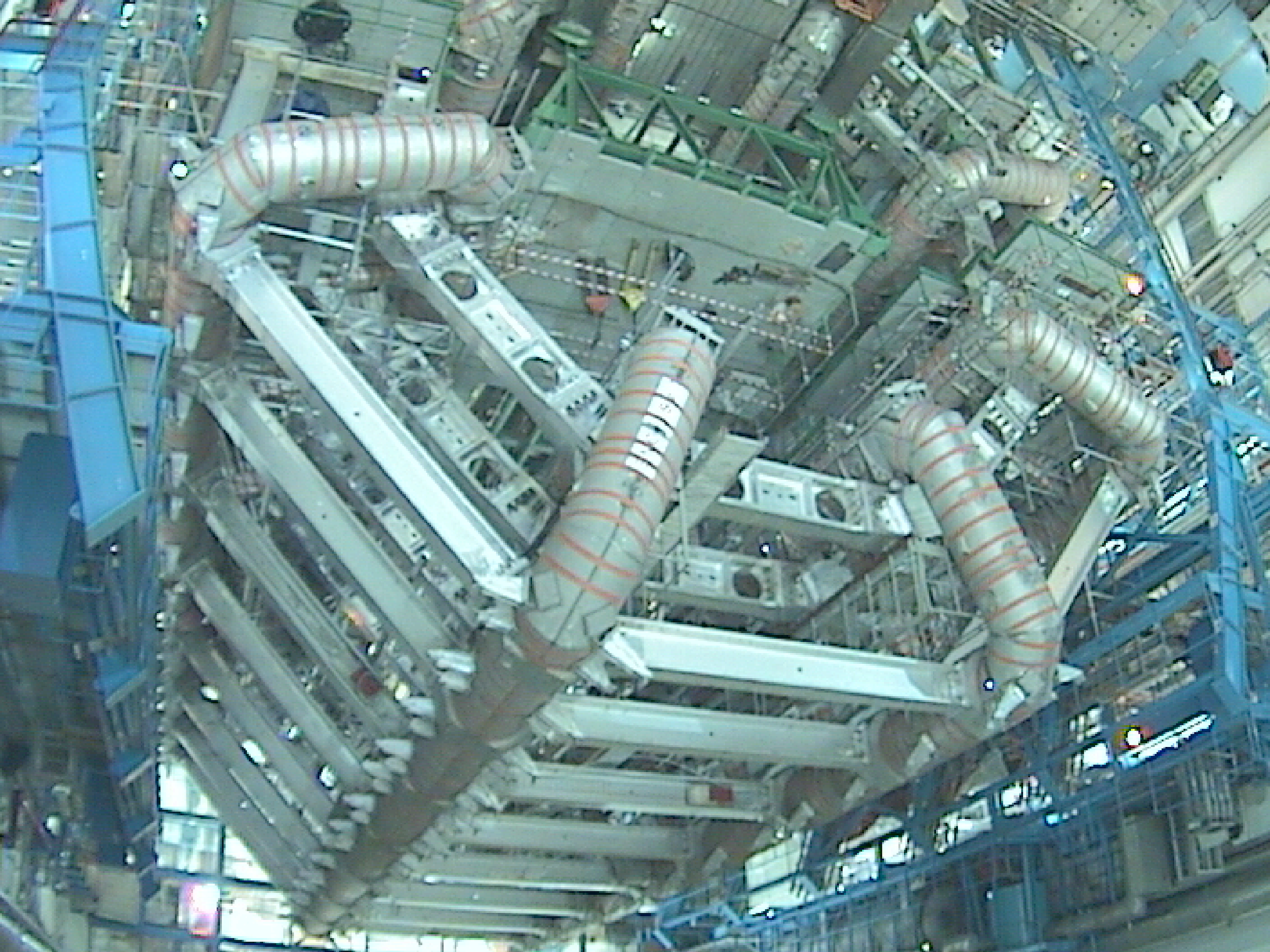


Coming to CERN/Geneva in 2007: the LHC proton–proton collider at 7+7 TeV

speed of protons: c – 10 km/h







Fabiola Gianotti (ATLAS) e Carlo Azeglio Ciampi (Italia)
« Se non troviamo il bosone di Higgs, la teoria è falsa ! »

Frontier:
The meaning of identity

- What sets quark & lepton masses? *New physics!*
  Why isospin?
- What is CP violation telling us?
- The role of neutrinos
- Will new kinds of matter show us pattern?
  sterile neutrinos, dark matter, superpartners,

Mendele'ev didn't know about noble gases

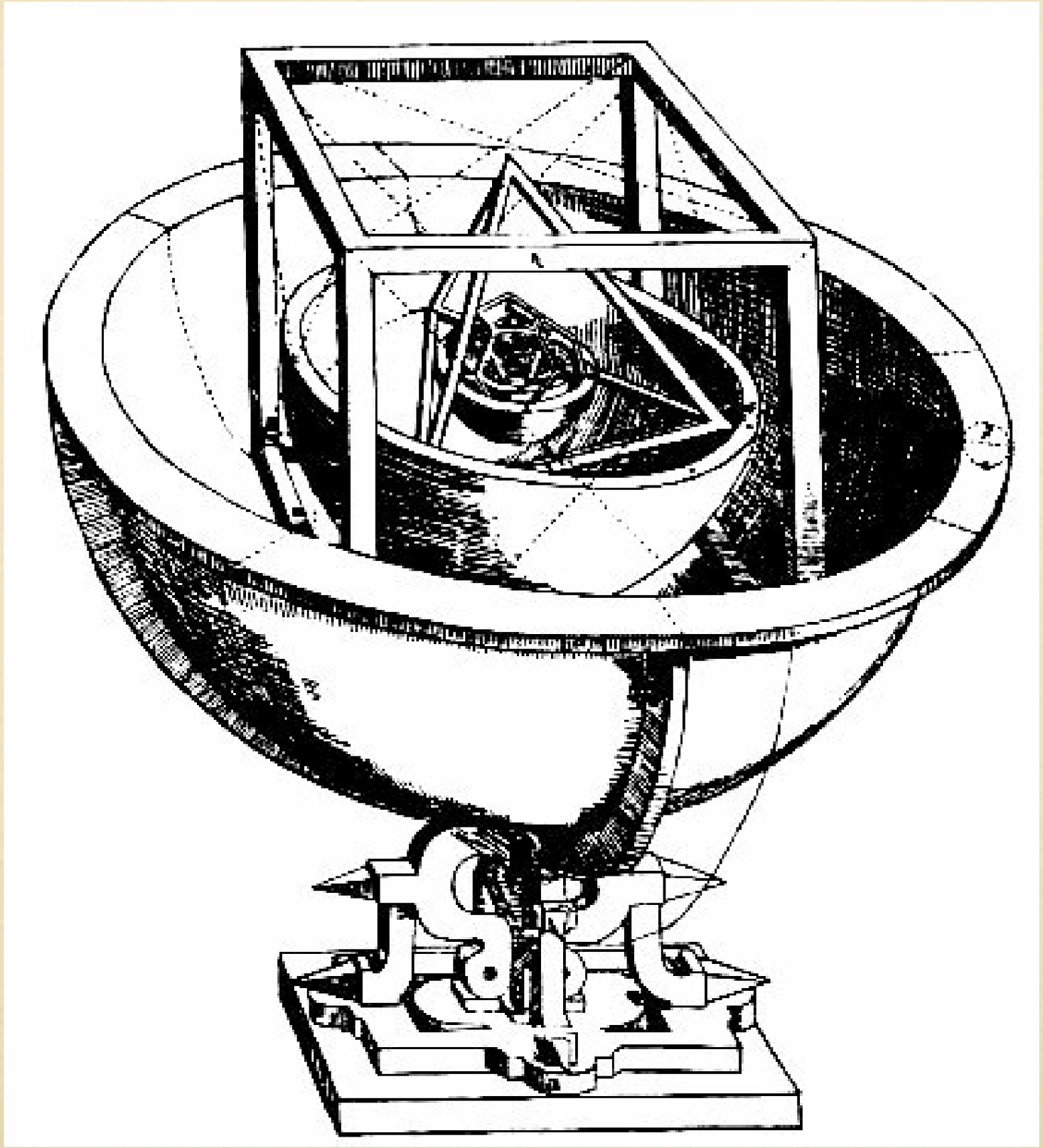
Dark Matter Precedent:
Discovery of the Noble Gases

"Nitrogen" from atmosphere 1/2% heavier than extracted from N-bearing compounds.

Hypothesis: an unknown ingredient in the air.

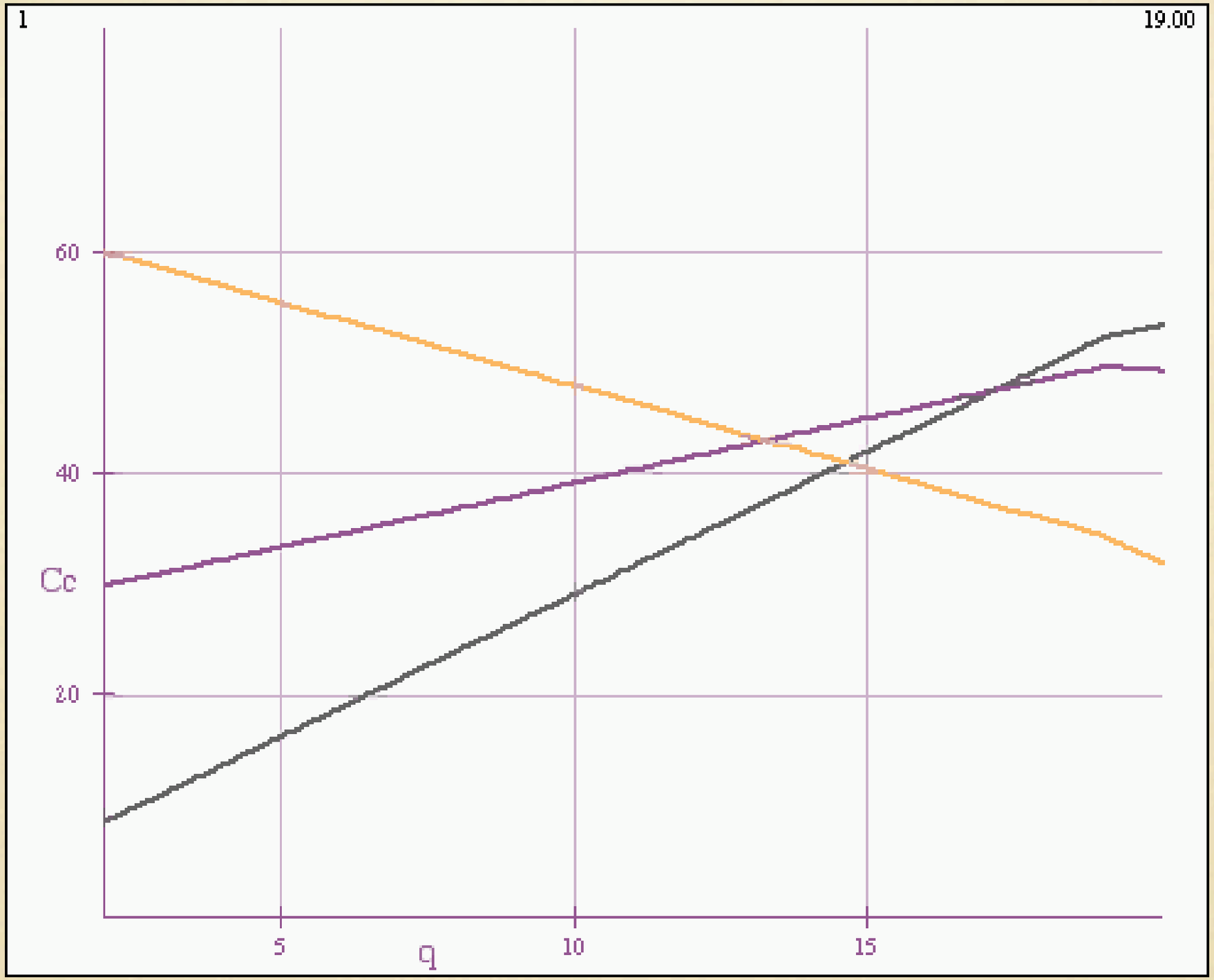
"... the improbability that a gas surrounding us on all sides, and present in enormous quantities, could have remained so long unsuspected."

Lord Rayleigh



Frontier:
The Unity of Quarks and Leptons

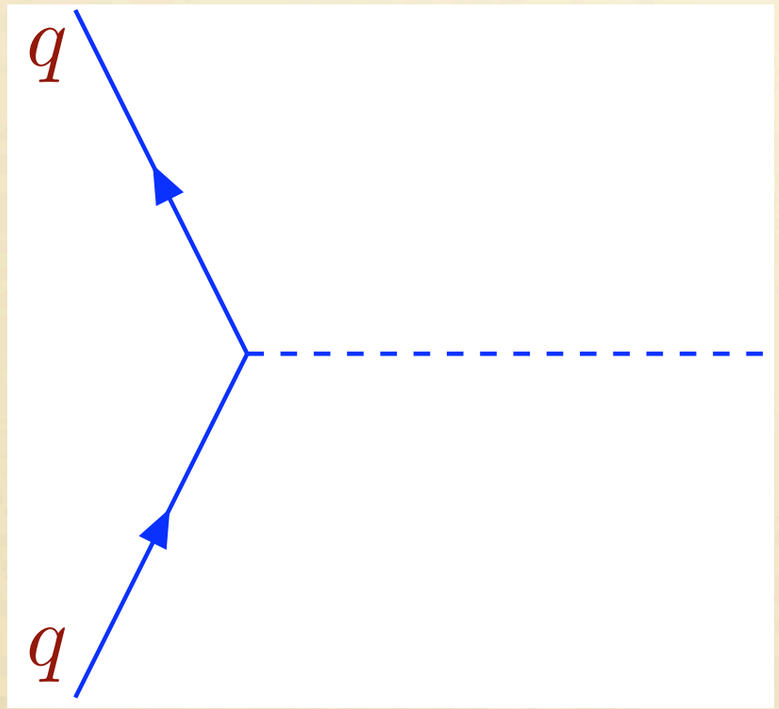
- What do quarks and leptons have in common?
- Why are atoms neutral?
- Which quarks paired with which leptons?
- Extended quark–lepton families: proton decay!


1
19.00
60
40
20
Cc
5
10
15
q

Gravity rejoins Particle Physics rejoins Gravity

Natural to neglect gravity …

$$G_{\text{Newton}} \textit{ small} \iff M_{\text{Planck}} = \left(\frac{\hbar c}{G_{\text{Newton}}}\right)^{\frac{1}{2}} \approx 1.22 \times 10^{19} \text{ GeV } \textit{large}$$



$$\sim \frac{E}{M_{\text{Planck}}}$$

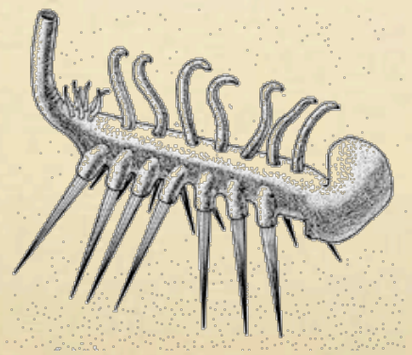
Estimate $B(K \to \pi G) \sim \left(\frac{M_K}{M_{\text{Planck}}}\right)^2 \sim 10^{-38}$

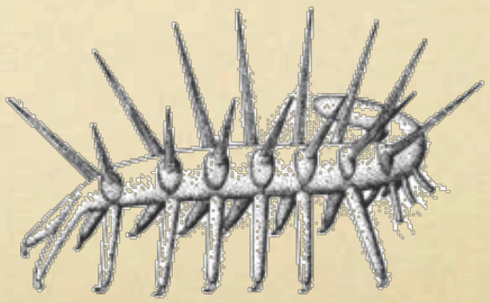
A Chronic Dull Headache ...
... for thirty years

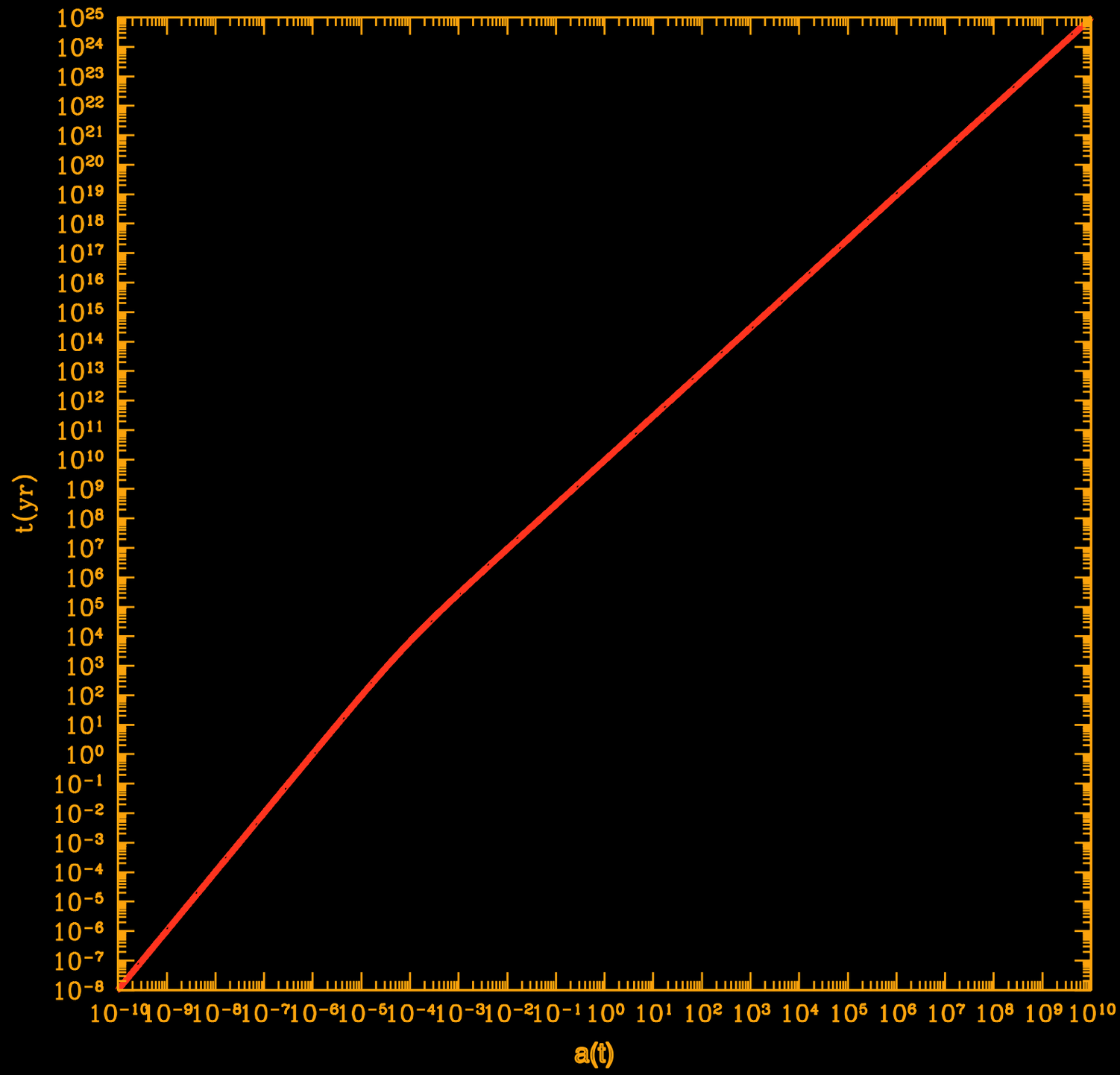
- Higgs field fills all of space with energy density 10^{25} g/cc
- But empty space weighs next to nothing: $< 10^{-29}$ g/cc
- Evidence that vacuum energy is present (accelerating universe) recasts problem

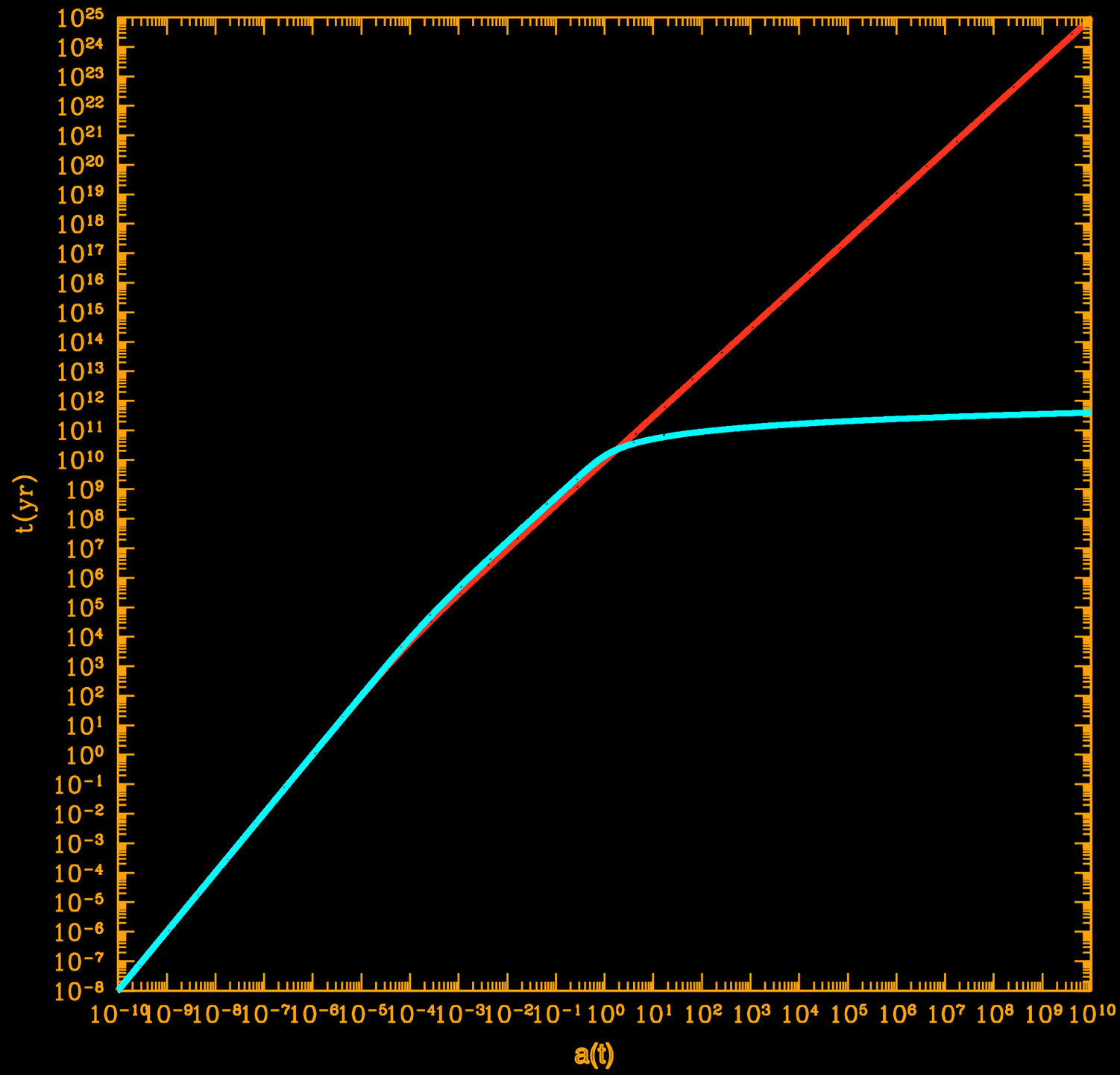
Implications for ...
the fate of the universe

- The fossil record is sparse ...
- We read it imperfectly, influenced by our world-view (of the moment)
- Enrich fossil record [observations]
- Improve theory [experiments]





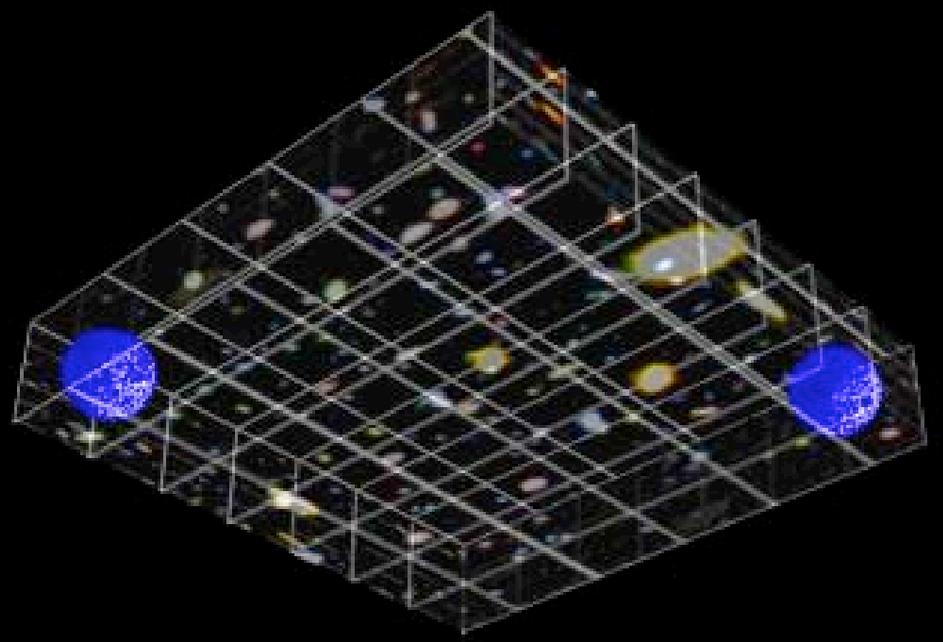

t(yr)
10^25
10^24
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-10 10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^10
a(t)


t(yr)
10^{25} 10^{24} 10^{23} 10^{22} 10^{21} 10^{20} 10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{0} 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8}
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10}
a(t)

Frontier:
A New Conception of Spacetime

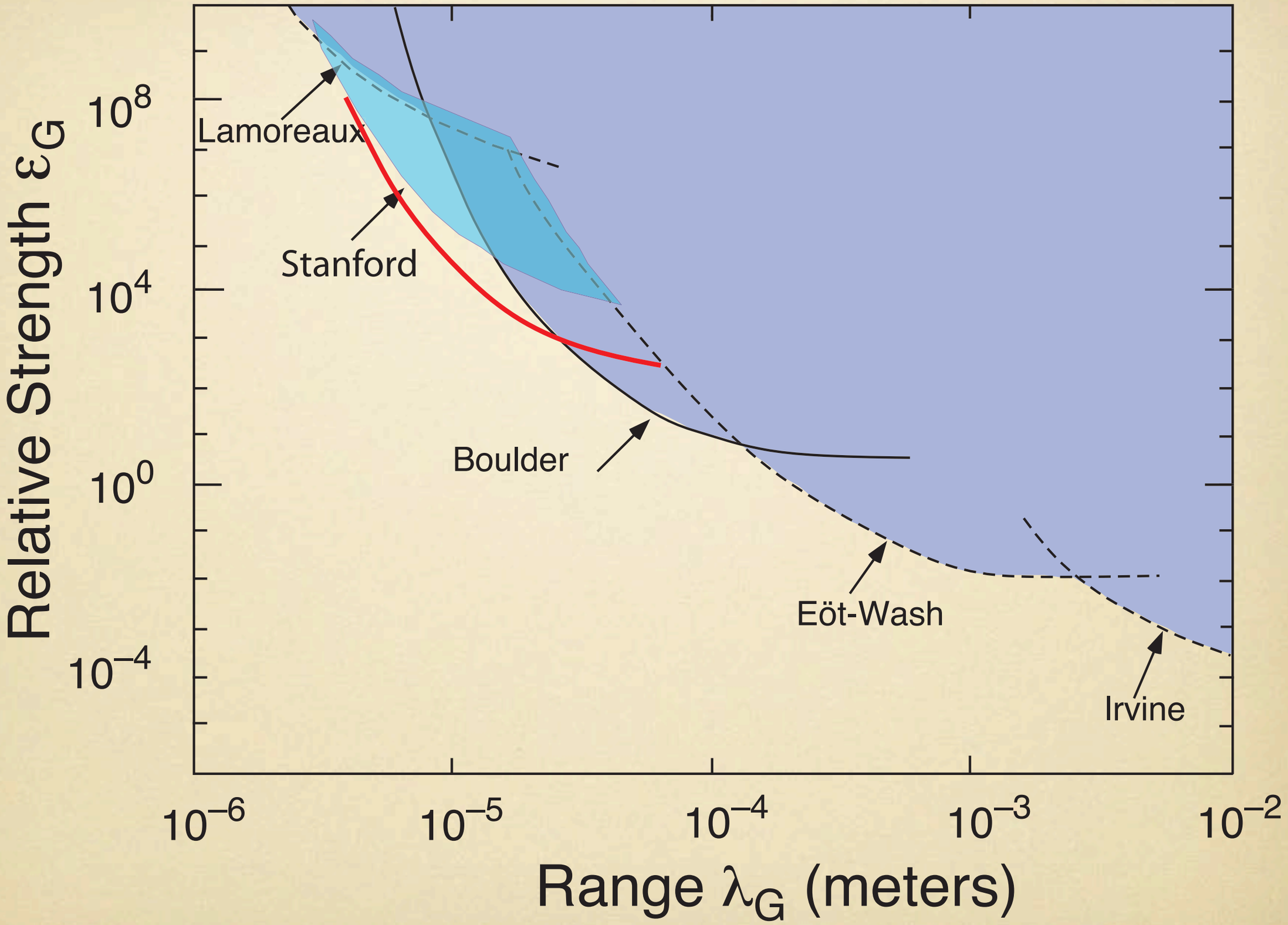
- More space dimensions?
- What is their size? their shape?
- How do they influence our world?
- How can we map them?

(string theory requires 9 or 10)



Is Newton's Law True Forever?

- Inverse square law for gravity is tested over a large, but finite, range
- Not tested below 0.1 mm, equivalently above 10 meV (compare 1 TeV for other forces we know)
- *n* extra dimensions: $1/r^{2+n}$


Relative Strength ε_G
10^{8}
10^{4}
10^{0}
10^{-4}
Lamoreaux
Stanford
Boulder
Eöt-Wash
Irvine
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Range λ_G (meters)

Frontier:
A New World of Accelerators

- Refine standard electron and proton technologies: LHC, ILC, VLHC, ...
- Develop exotic accelerator technologies CLIC, laser / plasma acceleration
- Exotic particles: γγ, μ storage ring, μμ, β-beams, ...

Frontier:

Escaping our preconceptions

- How is our thinking too narrow?
  Quantum field theory / CPT / Locality ...
- Do the same laws hold at all times and places?
- Fundamental asymmetries in the laws?